



Volume 24, 2025

AN EMPIRICAL STUDY OF IMMERSIVE LEARNING USING DESKTOP AUGMENTED REALITY IN THAI PRIMARY EDUCATION

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ABSTRACT

Aim/Purpose	The study investigated how immersive learning environments could be used to encourage student engagement and reuse intentions by integrating desktop augmented reality (AR) into the classroom among primary school students.
Background	This paper addresses the potential applications of immersive technology for younger learners and understanding in Thai primary education by exploring the implementation of desktop AR as an immersive learning tool. Despite the potential benefits of immersive learning and the development of immersive learning systems for older learners, investigating immersive learning tools for younger learners has lagged behind technological development. This can be attributed partly to the cost and technical form of early immersive technologies.
Methodology	By conducting a multi-stage research and development that evaluates the practical application of desktop AR in a classroom setting on student engagement and

Accepting Editor Martin D Beer | Received: October 27, 2024 | Revised: December 17, 2024; January 13, February 5, February 21, March 14, March 16, 2025 | Accepted: March 30 19, 2025.

Cite as: Laoharutanun, O., Songkram, N., & Hoonsopon, D. (2025). An empirical study of immersive learning using desktop augmented reality in Thai primary education. *Journal of Information Technology Education: Research*, 24, Article 15. <https://doi.org/10.28945/5483>

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reuse intention, the study used an explanatory sequential mixed methods research design, pairing an experimental trial and survey with expert interviews. A desktop-based AR software application designed to teach science was developed based on standard curricula and materials for the appropriate age group. The trial and survey were conducted among Grade 6 students in three primary schools (n=480).

Contribution	This research has academic, practical, and policy implications. The academic contribution of the research lies in the linkage of the 5E instructional framework and immersive learning. The research's practical application lies in the development and commercialization of an immersive learning application targeted to the specific needs of primary school students in Thailand. The research's policy contribution lies in its illustration of the potential of immersive learning for the classroom. By conducting research into immersive learning at the primary level, the researcher can provide information to policymakers refining the national core curriculum to meet the needs of 21st-century learning in Thailand. While this is only one data point in the revision of a large curriculum, this kind of information could help promote advanced learning in similar emerging countries.
Findings	The survey findings revealed that presence and embodiment did not significantly influence user engagement, but enjoyment and novelty did have a significant influence. Enjoyment, novelty, and user engagement had a significant effect on reuse intentions for the software. Expert interviews were conducted with science teaching experts from three primary schools. Their views of the software were positive, but practical implementation issues, such as the cost of the software, were noted. The implications of the study include differences between younger and older learners in user engagement and that there may be practical limitations on the implementation of immersive learning at the primary level.
Recommendations for Practitioners	The study contributes pragmatically by illustrating both the value that immersive learning could provide at the primary level and the limitations of implementing immersive learning. Furthermore, the study suggests that desktop-based immersive learning may not be as engaging as mobile device-based immersive learning.
Recommendations for Researchers	The study has contributed to the literature by investigating immersive learning in a relatively unusual group. It has shown that primary learners may be different in terms of the factors in their engagement and what determines their reuse intentions for technology than older learners.
Impact on Society	The integration of desktop AR in Thai primary education has the potential to transform educational practices and outcomes by enhancing student engagement and understanding through immersive learning experiences. AR can help bridge educational gaps, particularly in underserved regions. This technology encourages active participation and collaboration among students, fostering critical thinking and problem-solving skills essential for the 21st century. Furthermore, as students become more adept at using advanced technologies, they are better prepared for future workforce demands, contributing to a more skilled and innovative society. Ultimately, the successful implementation of AR in education can lead to a more informed and capable citizenry, driving social progress and economic development.

Future Research	Additional research into how younger students engage with immersive learning environments would be appropriate to understand better some of the different findings that occur when younger students are investigated. Another opportunity for further research is the comparison of desktop-based vs mobile-based to evaluate different effects on user engagement and learning outcomes.
Keywords	augmented reality, immersive learning, primary education, reuse intention, user engagement

INTRODUCTION

Potential applications of immersive technologies, such as augmented reality (AR) and virtual reality (VR), are an exciting area of development. Immersive technologies facilitate embodied learning, in which the individual's senses and physical body become engaged in the learning process as they apply their theoretical knowledge in the physical world (Lindgren & Johnson-Glenberg, 2013). At the university and professional level, immersive technologies such as VR have been used for experiential learning, for example, surgical training (de Leo et al., 2014). Such virtual learning environments, which are long-established, allow learners to apply their theoretical knowledge and develop the physical skills required to implement this knowledge (Tang et al., 2022). In other words, immersive technologies can be used to create an immersive learning environment where learners are both cognitively and physically engaged in the learning process (Oprean & Balakrishnan, 2020).

The promise of immersive learning is beginning to translate into market implementation. According to one estimate, the global market value of so-called 'metaverse education' was \$2.5 billion as of 2024 (Statista, 2024). This market is expected to grow rapidly at a rate of 46.14% annually up to 2030, leading to an estimated market value of \$24.7 billion by 2030 (Statista, 2024). However, this implementation is not equally distributed internationally. According to recent statistics, about 40% of the immersive learning market is in the United States, with China (\$283 million) being the second largest market (Statista, 2024). In Thailand, the market is estimated at only \$9.9 million as of 2024 but is expected to rise to \$107.8 million by 2030 (Statista, 2024). Thus, while still small, immersive learning will be a much larger market in a few years. The research reported here focused on how to develop immersive learning tools for an underserved market: elementary learners.

Despite the potential benefits of immersive learning and the development of immersive learning systems for older learners, investigating immersive learning tools for younger learners has lagged behind technological development. This can be attributed partly to the cost and technical form of early immersive technologies. Until the development of relatively inexpensive VR systems, such as the Oculus Rift, and the widespread adoption of smartphones in the early to mid-2010s, immersive technologies were expensive and difficult to use (Hung et al., 2021). The introduction of Pokémon Go! in 2016 marks the point where immersive technologies entered the entertainment sphere (Bueno et al., 2020). There have been some studies that have highlighted the potential of immersive learning for young learners. The technology can be used to facilitate 'virtual field trips,' where students use AR and VR to view different places (Han, 2020). Immersive technology can also be used to facilitate science learning by enabling experimentation (Kang et al., 2021; Lindgren et al., 2013, 2016). However, there are still unanswered questions about how virtual technologies affect the learning process, especially at the elementary level.

Immersive learning has been promoted internationally as a revolutionary tool for education at all levels (Frehlich, 2020). Although the research on immersive learning at the elementary level is sparse, there have been studies undertaken in countries including South Korea (Han, 2020), Pakistan (Afnan et al., 2021), Malaysia (Alalwan et al., 2020) and the United States (Lindgren et al., 2016) among others. Thus, the question of how immersive learning can be used at the elementary level to promote

learning is of international interest. As Alalwan et al. (2020) pointed out, the perspective from developing countries may be different from earlier studies in high-income countries due to the need to implement immersive learning using less expensive equipment than the full virtual reality (VR) or projector-based AR systems used by others. By studying immersive learning environments in the Thai elementary classroom, this research contributes to the international body of knowledge.

Immersive learning has been recognized as an important approach to learning in the future of Thailand (Phakamach et al., 2022; Soodtoetong & Rattanasiriwongwut, 2024). The use of a metaverse, or social immersive learning, has been proposed as a future improvement to teaching and learning among learners of all ages (Phakamach et al., 2022). Authors have also pointed to the importance of virtual reality in science, technology, engineering, and mathematics (STEM), which is an area of learning that is both critical for Thailand's future economic development and where Thailand underperforms (Soodtoetong & Rattanasiriwongwut, 2024). Despite the promoted importance of immersive learning, there has been limited research in the elementary context. Like the international literature, the studies that have been conducted in Thailand focus on secondary and tertiary education (Jantakoon et al., 2019; Soodtoetong & Rattanasiriwongwut, 2024; Watthanapas et al., 2023; Yamyim et al., 2022). Thus, this research contributes to the literature by investigating how immersive learning can be used in the elementary classroom.

This study investigated the question of how immersive learning environments could be used to encourage learning engagement and reuse intentions among primary school students in Thailand. A desktop immersive learning environment was developed and deployed in a pilot test. Objectives for the test included (1) developing and testing the immersive learning framework, (2) investigating how the immersive learning framework influenced engagement and reuse intention, and (3) developing recommendations for improvement and implementation of desktop learning environments based on the outcomes of the pilot test and interviews with primary educators. These objectives were investigated first through the lens of a literature review.

LITERATURE REVIEW

THEORETICAL FRAMEWORK: USER ENGAGEMENT AND REUSE INTENTIONS

The theoretical framework connects user engagement for AR and reuse intentions. User engagement in technology refers to a cluster of cognitive and emotional processes that users experience in relation to the technology they use (O'Brien & Toms, 2008). User engagement may be viewed through different theoretical lenses, including flow theory (Csikszentmihalyi, 1990) and the philosophy of experience (Dewey, 1938). However, a wide array of other contributions have formalized a theory of user engagement as it applies to modern technology (O'Brien, 2016). User engagement can be formally defined as "a category of user experience characterized by attributes of challenge, positive affect, durability, aesthetic and sensory appeal, attention, feedback, variety/novelty, interactivity, and perceived user control" (O'Brien & Toms, 2008, p. 941). User engagement contributes to user behaviors such as disengagement (where users stop using the technology) and reengagement (where users choose to use the technology again) (O'Brien & Toms, 2008).

A particularly useful approach to understanding user engagement for this research is flow theory, which is focused on flow activities (O'Brien, 2016). Flow activities are activities that are emotionally and cognitively enjoyable and absorbing, such that those who engage in the activity will continue just for the enjoyment of the activity (O'Brien, 2016). Flow experience is an important aspect of learning through technology, as without sufficient engagement in the material and enjoyment, users will not continue to use the technology, limiting their learning outcomes (Sun et al., 2017). Additionally, flow experience is itself an important part of the cognitive learning process (Csikszentmihalyi, 1990). Furthermore, aspects of the flow experience, including enjoyment and novelty, contribute to reuse inten-

tions for technology (Venkatesh et al., 2012). Reuse intentions are different from initial usage intentions for technology because they are based on the user's prior experience with the technology, not only on their preliminary evaluation of the technology (Jahn et al., 2021). Therefore, there is a good reason to investigate the connection between user engagement and reuse intentions, as they are theoretically linked through flow theory and other theories.

AUGMENTED REALITY (AR) AND IMMERSIVE LEARNING

Augmented reality (AR) is one of a cluster of so-called immersive technologies that blend computer-generated visual and sound elements with the physical environment to create a specific sensory environment (Suh & Prophet, 2018). AR uses a combination of computer-generated outputs overlaid across the physical environment to modify this environment and enable different types of environmental interaction to take place (Tang et al., 2022). While AR and other forms of immersive technology have been used in a variety of different contexts, according to Tang et al. (2022), the introduction of immersive technology to education is relatively recent. The introduction of less expensive and more powerful AR systems has enabled the introduction of AR as a tool for immersive learning, which uses immersive technologies to promote experiential learning in previously inaccessible ways (Kuhail et al., 2022). Although AR is commonly implemented today as a mobile phone or other mobile device-based function (Kuhail et al., 2022), there are still some significant advantages to desktop-based AR, including classroom presence and greater display and rendering capabilities compared to mobile devices (Prit Kaur et al., 2022).

While AR has been posited to have a potentially revolutionary effect on primary education (Basumary & Maity, 2023), it is unclear to what extent AR is actually used in classroom contexts. Basumary and Maity (2023), who conducted a literature review on AR in primary education, showed that it could have significant effects on learner engagement, enjoyment, and learning outcomes. However, significant technical and resource barriers and problems like learner overload were also identified. Additionally, the authors identified relatively few studies (including only 25 journal articles over their 10-year period of 2012-2021), suggesting a paucity of research compared to other AR learning contexts. Another study found that AR learning applications for young learners were generally non-interactive and unfocused (Afnan et al., 2021). Lack of time, resources, and attention, along with lack of teacher knowledge, were also identified in another study as barriers to AR use in elementary schools (Alalwan et al., 2020). Therefore, despite the potential role of AR in elementary learning, to date, its adoption has been limited due to these barriers. Of particular interest here is user engagement in immersive learning.

USER ENGAGEMENT IN IMMERSIVE LEARNING

Learner engagement can be defined as "... a collection of mindfully goal-directed behaviors and reflections demonstrated to indicate a meaningful and deep involvement in learning activities" (Ke et al., 2016, p. 1181). Learner engagement can be viewed as a combination of cognitive, emotional, and behavioral elements, which together contribute to the extent to which learners will participate in and expend effort toward the learning objectives (Halverson & Graham, 2019). This research focuses on a specific type of learner engagement – user engagement in the immersive learning system or, in other words, the degree to which an immersive learning system user participates in and becomes involved with the learning activities (Oprean & Balakrishnan, 2020). Oprean and Balakrishnan's (2020) immersive learning framework argues that there are four dimensions of the immersive learning environment itself that influence user engagement: presence, embodiment, enjoyment, and novelty. These four dimensions can each potentially contribute to user engagement.

User presence, or the sense of 'being' physically in the AR location or environment (Oprean & Balakrishnan, 2020), has been identified as a factor in user engagement in other immersive learning studies. One of these studies investigated the use of desktop AR-based 'remote field trips,' in which students visited sites using AR (Han, 2020). Students identified a higher sense of presence than tradi-

tional (non-AR) virtual tours, which was associated with a greater sense of engagement in student interviews. A second adult learning study, which investigated virtual visits to art museums, also identified a greater sense of presence (especially social presence) as a factor in user engagement (Elwood, 2018). Therefore, the first hypothesis is:

H1: Presence has a positive effect on user engagement in the immersive learning environment.

User embodiment can refer to several different aspects of embodied cognition, such as physical embodiment within the virtual environment (Kilteri et al., 2012) or social embodiment or the sense of being ‘socially’ within a space (Barsalou et al., 2003). Evidence for the importance of embodiment in user engagement comes from projects such as the METeor simulation project, which uses projector-based AR to teach elementary students about planetary systems (Lindgren et al., 2013, 2016). These studies have compared desktop simulation and whole-body simulation for the same content, showing that groups that experienced the whole-body simulation had higher levels of enjoyment and engagement in the learning process. The IMAGINE interactive smart space provides more evidence (Gelsomini et al., 2020). This study illustrated that embodied learning increased engagement and that it was higher among the experimental group. Therefore, the second hypothesis is:

H2: Embodiment has a positive effect on user engagement in the immersive learning environment.

Enjoyment simply refers to the perceived fun involved in using the system (Oprean & Balakrishnan, 2020). Enjoyment is routinely associated with both learner and user engagement. One experiment on ‘serious games’ found that enjoyment of a simulation was associated with interest and engagement in the learning material, regardless of whether the simulation content was gamified or not (Imlig-Iten & Petko, 2018). Another study investigated learner engagement in foreign language learning (Guo, 2021). Guo (2021) found that enjoyment of foreign language learning was directly associated with learner engagement. The study also found evidence of a potential bidirectional or cyclical relationship in which feedback between enjoyment and learner engagement increased both. Based on this evidence, the third hypothesis is stated as:

H3: Enjoyment has a positive effect on user engagement in the immersive learning environment.

Novelty refers to the extent to which the system is viewed as new or interesting compared to past experiences (Oprean & Balakrishnan, 2020). Novelty has less research focus than other aspects of the immersive learning environment. One study on immersive music learning at the primary level suggested (but did not prove) that the novelty of the learning environment contributed to higher levels of interest and engagement among pupils (Innocenti et al., 2019). A study that investigated immersive learning in undergraduate science learning found that there were initially high levels of user engagement but did note that these may fall over time as the technology becomes more familiar (Salar et al., 2020). Based on these studies, the research contributes to understanding novelty by investigating the following hypothesis:

H4: Novelty has a positive effect on user engagement in the immersive learning environment.

While user engagement is likely to have an effect on reuse intention for technology (which is discussed in more detail below), learner enjoyment and novelty may also influence reuse intention. These factors are discussed in the next section.

FACTORS IN REUSE INTENTION

A further outcome of interest is reuse intention for the technology, or the user’s desire to and conscious cognition that they will use the technology again (Choi & Sun, 2016). Unlike the initial usage intention, reuse intention (also sometimes modeled as continuance intention) depends not just on the technical aspects of a given system but also on their prior experience in using the system (Choi &

Sun, 2016). It is expected that two aspects of the user's experience with the system will influence reuse intention: enjoyment and novelty.

There is some evidence that enjoyment will influence reuse intention, although this evidence is sparse. One study investigated e-learning for an open university course (Rodríguez-Ardura & Me-seguer-Artola, 2016). These authors used the flow construct, which is a composite of immersion, enjoyment, and loss of a sense of time during the system usage. The authors found that there was a direct relationship between the experience of flow and the intention to reuse the technology, as well as an indirect relationship through satisfaction. Another study investigated reuse intentions for immersive games (Bueno et al., 2020). The authors found that enjoyment directly influenced the intention to reuse the technology. These studies provide some support for the influence of enjoyment on reuse intentions for immersive technology. Therefore, the fifth hypothesis is proposed:

H5: Enjoyment has a positive effect on reuse intentions for the immersive technology.

There is limited evidence for the role of novelty in reuse intentions for immersive technologies, in part because novelty does not yet have an accepted definition or measurement. One group of authors investigated Pokémon Go! (a leading AR-based game) found that the trendiness of the game did not contribute to reuse or continuance intentions (Hamari et al., 2019). On the other hand, an investigation of AR-based try-on technology for online clothes shopping found that prior experience could have an influence; specifically, the authors found that prior experience moderated the relationship between environmental embedding and immersion (Song et al., 2019). These studies suggest but do not prove that novelty may influence the intention to reuse immersive technology in general. An additional research gap is that this evidence does not come from immersive learning but from purely hedonic activities (gameplay and shopping). The sixth hypothesis is therefore included as an exploratory investigation:

H6: Novelty has a positive effect on reuse intentions for the immersive technology.

The evidence for the influence of user engagement on reuse intention is ambiguous and limited. Theoretically, AR is argued to have an effect on the emotions of the user, including engagement with the content shared through AR (Soon et al., 2023). This effect could contribute to the user's desire to reuse or continue to use the technology. However, empirical evidence is limited to only a few studies, of which only one took place among child learners. According to research on the IMAGINE immersive learning system, students who used the immersive system were more engaged in learning and more likely to express a desire to use the system again compared to other students (Gelsomini et al., 2020). These findings were derived from reflective essays completed by students following the trial rather than tested experimentally. So, although this study provides some evidence for such a link, it does not prove it comprehensively.

A study among adult users of massive open online courses (MOOCs) found that learner engagement was positively associated with learner persistence (including reuse and continuance intentions) (Jung & Lee, 2018), but this study was conducted among adults. Another study which investigated informal online learning among adults suggested that learning engagement was one of the contributing factors to student continuance intentions (Wang et al., 2022). Like the study of Jung and Lee (2018), Wang et al. (2022) were investigating adult learners. It is not surprising that there is no direct evidence for this relationship in studies of AR use in elementary schools, given that the literature on this topic is sparse (Basumatary & Maity, 2023). This limitation offers the opportunity to investigate a final hypothesis, which states:

H7: User engagement has a positive effect on reuse intentions for the immersive technology.

The conceptual framework (Figure 1) illustrates the relationships identified within the literature review. These hypotheses were evaluated in the quantitative stage of the research process, as well as investigated in the qualitative research. The methods used are described in the next section.

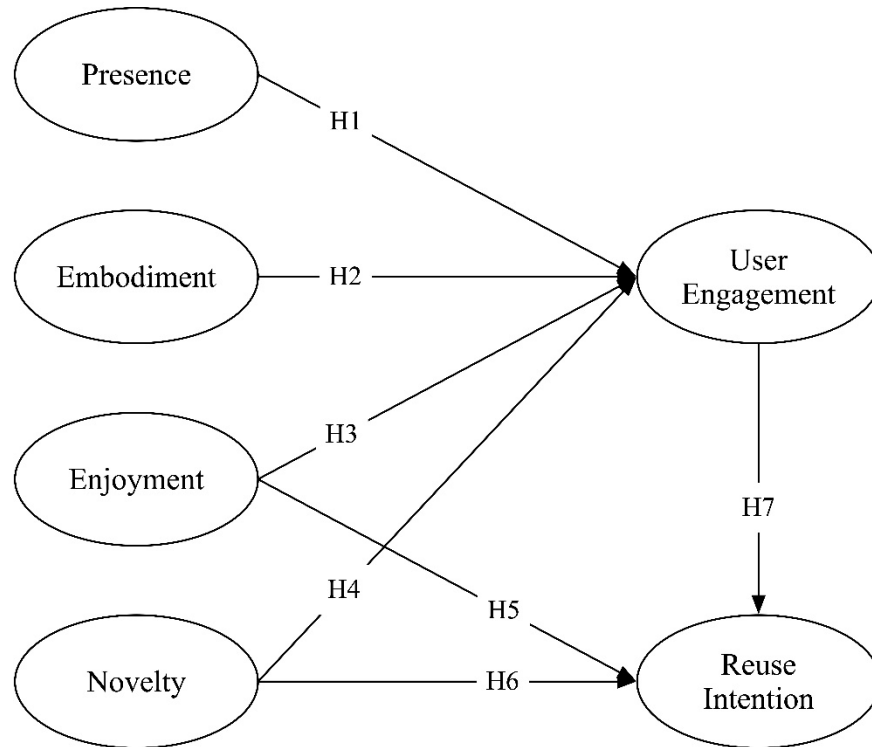


Figure 1. Conceptual framework

RESEARCH METHODOLOGY

The research used an explanatory sequential (QUAN → qual) mixed-method design. The first phase of the research was system development and testing conducted in a school setting, with quantitative data collected using a pre/post approach. The second phase used expert interviews to examine the outcomes and potential for implementation within other primary schools. Here, the quantitative research is described, followed by the quantitative research.

QUANTITATIVE RESEARCH

System development

The first phase of research began with the development of a desktop-based AR game. The game was designed as an educational game with a focus on Space Technology. Questions were drawn from the Institute for the Promotion of Teaching Science and Technology (IPST) primary science textbooks. Questions were adaptively staged so that as students got more answers correct, they would receive harder questions. The game used controls and interaction techniques similar to leisure games; for example, users could choose and customize avatars (within limits to keep avatars appropriate for classroom play). The in-game content is regularly refreshed to promote novelty and enjoyment. The game was developed using the Desktop AR software development kit (SDK) and was alpha and beta tested using subject matter experts to ensure accuracy and evaluate gameplay.

Population and sample

Following the development of a trial version of the game above, a series of primary schools in different areas of Thailand were selected as test sites. These schools included two public schools and two private schools of similar size. Students from Grade 6 (Pratom 6) were selected using a quota sampling approach to ensure equal representation of each school ($n = 120$ per school) and gender representation ($n = 240$ for girls and boys). The final sample size included 480 students.

Data collection

The trial version of the software was introduced in science and technology classes at approximately the same time, and students were given one hour to play and experiment with the tool. The survey collected information on student experience with AR and VR games, as well as the dimensions of the study. Construct items were measured using a 7-point Likert scale, as this typically offers adequate discrimination between responses around the center scale (Pimentel, 2019). This survey, which was developed based on previous instruments (Bueno et al., 2020; Kilteni et al., 2012; Talukdar & Yu, 2024; Verhulst et al., 2021), is summarized in Table 1.

Table 1. Summary of student engagement survey

Construct	Items	Source
Presence	P1. I felt present in the virtual space. P2. I was completely captivated by the virtual world. P3. The virtual world felt real. P4. I had a sense of being there in the virtual world.	Verhulst et al. (2021)
Embodiment	EM1. I felt like I was actually within the game. EM3. I felt like my body was in the space where the game was being played. EM3. I felt like I was standing behind the player in the game, with their viewpoint. EM4. I felt like the game body was my own body. EM5. I felt like I was in control of the game. EM6. I could do what I wanted in the game.	Kilteni et al. (2012)
Enjoyment	EN1. I found this experience enjoyable. EN2. This game let me experience something I don't in everyday life. EN3. I had fun with this game.	Bueno et al. (2020)
Novelty	N1. This experience was original. N2. This experience was different from what I had experienced before. N3. This is a new kind of learning experience for me.	Talukdar and Yu (2024)
User engagement	U1. I was mentally involved in the story while experiencing it. U2. I wanted to learn how the story ended. U3. The story affected me emotionally. U4. I was touched by the experience.	Adapted from Oprean and Balakrishnan (2020)
Reuse intention	RI1. I would like to repeat this experience. RI2. I would like to see more experiences like this. RI3. I plan to look for more kinds of experiences like this. RI4. I plan to tell my friends about this experience.	Verhulst et al. (2021)

Data analysis

The data analysis process began with an investigation of the scales, investigating internal consistency using Cronbach's alpha ($\geq .70$) and convergent validity using composite reliability (CR) ($\geq .70$) and average variance extracted (AVE) ($\geq .50$) (Hair et al., 2019). Confirmatory factor analysis (CFA) was then used to investigate factor structure in more detail (Brown, 2015). Descriptive statistics were calculated, and skewness and kurtosis were used to investigate normal distribution (Holcomb, 2017). A structural equation modeling (SEM) approach was used to test the hypotheses, as it is appropriate for analyzing the structure of complex models of latent variables (Kline, 2023). The outcomes of the

quantitative research were used to test the conceptual framework and hypotheses, as well as to direct the qualitative research.

QUALITATIVE RESEARCH

Following the completion of the trial and data collection from students, a panel of elementary school science and technology teaching experts (n = 3) was selected. These experts had wide-ranging qualifications and experience in science teaching at the primary school level and were up to date with current practices. Experts were selected from the participants in a broader study on immersive technology and included teachers who had implemented immersive learning in the classroom and/or who had been tasked with investigating its implementation in the school.

Interviewees were given a trial version of the software to evaluate prior to the interviews. An interview guide (Table 2) was prepared, addressing questions surrounding the use of immersive technology in teaching and the experts' impressions of the software and its suitability for use in their schools. Following data collection, qualitative content analysis (Mayring, 2022) was used to analyze the interview transcripts and provide summary assessments regarding the use of technology in schools and the suitability of the software.

Table 2. Summary of the interview guide

Area of interest	Question
Technology and teaching	1. Can you explain your school's use of information technology in curriculum and teaching?
	2. Do students in your school have access to technology like tablets or smartphones?
	3. Do students in your school routinely have private technology like tablets or smartphones?
	4. Does your school currently use immersive technologies, such as AR or VR, in teaching?
	5. Can you describe your school's experience with this technology?
	6. To what extent is it implemented in routine teaching practice?
	7. Is there resistance to the use of technology in your classrooms, and if so, what do you think is the cause of this resistance?
Application development testing	8. You were provided with a demonstration application that offer students the opportunity to engage in immersive learning for English vocabulary. To what extent did you have the chance to inspect this application?
	9. What are your thoughts on this application?
	10. What use do you think this application could be in your school?
	11. How could this application be made better for your school?
	12. Did you encounter any problems while using the application?
School use	13. Do you think your school would buy this application for students?
	14. If yes, why?
	15. If no, why not?
	16. How much per student would the school be willing to pay for a license for this application?

RESEARCH ETHICS

As the research was conducted with children, there were several ethical obligations structured into the research methodology. Consent was sought from both students and parents to ensure that stu-

dents truly consented to the research participation (Farrimond, 2016). This consent procedure included an information letter and permission slip (for parents), an in-class discussion, and active consent (for children). The in-class discussion, which was tailored to the children's age and knowledge of both the scientific process and AR technology, revolved around what they would be doing and how the researcher would use the knowledge gained (Oates, 2020). One of the key issues in educational research is that research may be 'opt-out' without having an opportunity to truly opt out (Farrimond, 2016). The research addressed this by ensuring that students had an alternative activity (an interactive language game) that did not detract from their learning if they chose not to take part and which was freely available to them. Additionally, children were given the chance to ask questions about the research prior to consent (Oates, 2020).

The results (presented in the following section) follow the process of the research, beginning with the quantitative findings and then transitioning to the qualitative findings.

RESULTS AND DISCUSSION

PARTICIPANT PROFILE AND DESCRIPTIVE STATISTICS

A total of 480 students participated in the trial and survey, including 120 students from each of the four schools. The participants were evenly divided between boys ($n = 240$) and girls ($n = 240$). All participants had at least some experience with AR and VR games. Forty-five students (9.4%) played once or twice a month, while 104 students (21.7%) played once or twice a week. Two hundred ninety-five students (61.5%) played between three and six times a week, while 36 students (7.5%) played AR or VR games every day.

Table 3 summarizes descriptive statistics for each item. Skewness and kurtosis ranged between -1 and 1 for all items, indicating an adequate level of univariate normal distribution (Hair et al., 2019).

Table 3. Descriptive statistics

	N	Mean	S.D.	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
P1	480	4.4771	1.24440	-.466	.111	.394	.222
P2	480	4.4354	1.24461	-.309	.111	.056	.222
P3	480	4.4479	1.23510	-.354	.111	.137	.222
P4	480	4.4208	1.28342	-.049	.111	.055	.222
EM1	480	4.4417	1.21436	-.144	.111	.030	.222
EM2	480	4.4500	1.21988	-.254	.111	.162	.222
EM3	480	4.4625	1.22374	-.280	.111	.392	.222
EM4	480	4.4333	1.24785	-.178	.111	.099	.222
EM5	480	4.4375	1.24304	-.187	.111	.074	.222
EM6	480	4.4729	1.19816	-.265	.111	.411	.222
EN1	480	4.4250	1.22543	-.116	.111	-.011	.222
EN2	480	4.4333	1.22761	-.192	.111	.119	.222
EN3	480	4.4104	1.21073	-.133	.111	.173	.222
N1	480	4.4229	1.19947	-.277	.111	.140	.222
N2	480	4.4083	1.24961	-.055	.111	.097	.222
N3	480	4.3833	1.27565	-.159	.111	.102	.222
U1	480	4.3417	1.24458	-.141	.111	.242	.222
U2	480	4.4271	1.24415	-.042	.111	-.059	.222
U3	480	4.3729	1.21254	-.195	.111	.210	.222

	N	Mean	S.D.	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
U4	480	4.3771	1.26849	-.157	.111	.092	.222
RI1	480	4.3958	1.20610	-.152	.111	-.027	.222
RI2	480	4.3417	1.25627	-.044	.111	.014	.222
RI3	480	4.4208	1.21146	-.072	.111	.217	.222
RI4	480	4.4042	1.25928	-.072	.111	-.003	.222

RELIABILITY, VALIDITY, AND FACTOR STRUCTURE

The second stage of analysis focused on the reliability, validity, and factor structure of the proposed constructs (Table 4). Using the pre-established alpha value ($\geq .70$), all constructs were shown to be adequately internally consistent. Additionally, the CR values ($\geq .70$) and AVE values ($\geq .50$) were all indicative of convergent validity for the constructs based on standard cut-off values (Hair et al., 2019). Therefore, adequate reliability and validity were found within the constructs.

Table 4. Reliability, validity, and structure of the constructs

Construct	Item	Factor loading	α	CR	AVE
Presence	P1	.89	.940	0.967	0.879
	P2	.94			
	P3	.94			
	P4	.94			
Embodiment	EM1	.95	.985	0.961	0.861
	EM2	.94			
	EM3	.95			
	EM4	.95			
	EM5	.95			
	EM6	.95			
Enjoyment	EN1	.94	.969	0.982	0.900
	EN2	.94			
	EN3	.94			
Novelty	N1	.94	.973	0.959	0.887
	N2	.95			
	N3	.94			
User engagement	U1	.95	.974	0.961	0.891
	U2	.93			
	U3	.96			
	U4	.92			
Reuse intention	RI1	.90	.966	0.964	0.871
	RI2	.91			
	RI3	.95			
	RI4	.96			

Note: α = Cronbach's alpha ($\geq .70$); CR = composite reliability ($\geq .70$); AVE = average variance extracted ($\geq .50$) (Hair et al., 2019)

Additionally, CFA was conducted to investigate the factor structure of each of the six latent constructs (Presence, Embodiment, Enjoyment, Novelty, User Engagement, and Reuse Intention). The measurement model is shown in Figure 2 (representing standardized estimates). A minimum factor

loading of .60 or higher was set to ensure that all items were loaded onto the appropriate latent construct. As summarized in Table 4 and represented graphically in Figure 2, all items are loaded onto the expected latent construct. Furthermore, the measurement model fit was good according to various measurement models (CFI = .986; TLI = .984; RMR = .012; RMSEA = .053). These values are all either above or below established thresholds (CFI \geq .95, TLI \geq .95, RMR $<$.08, RMSEA $<$.06), which indicate a good fit among a measurement model (Hair et al., 2019). Overall, these results indicated that the observed items adequately measured the intended latent constructs.

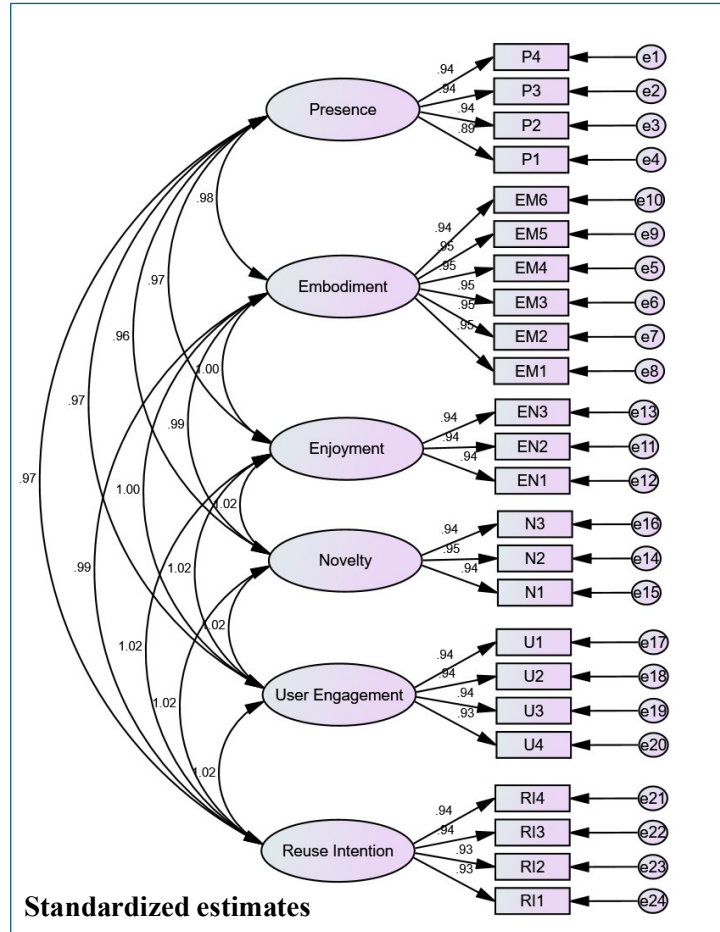


Figure 2. Measurement model of six constructs (presence, embodiment, enjoyment, novelty, user engagement, and reuse intention)

STRUCTURAL EQUATION MODELLING

The structural equation model (Figure 3) was used to investigate the causal relationships between the immersive learning environment, user engagement, and reuse intention. The model was well fitted (CFI = .985; TLI = .983; RMR = .012; RMSEA = .054), with values again all being above or below established thresholds for good fit (CFI \geq .95, TLI \geq .95, RMR $<$.08, RMSEA $<$.06) (Kline, 2023). The regression coefficients indicate that presence did not have a significant effect on user engagement ($\beta = -0.07, p > .05$), and neither did embodiment ($\beta = 0.02, p > .05$). However, enjoyment ($\beta = .43, p < .001$) and novelty ($\beta = 0.62, p < .001$) did have the expected significant effect. Enjoyment ($\beta = 0.43, p < .001$) and novelty ($\beta = 0.58, p < .001$) did have a significant effect on reuse intention.

User engagement ($\beta = 0.08, p < .05$) had a significant effect, but it was somewhat weaker than the others. These results are summarized in Table 5 as they form the basis for hypothesis test outcomes.

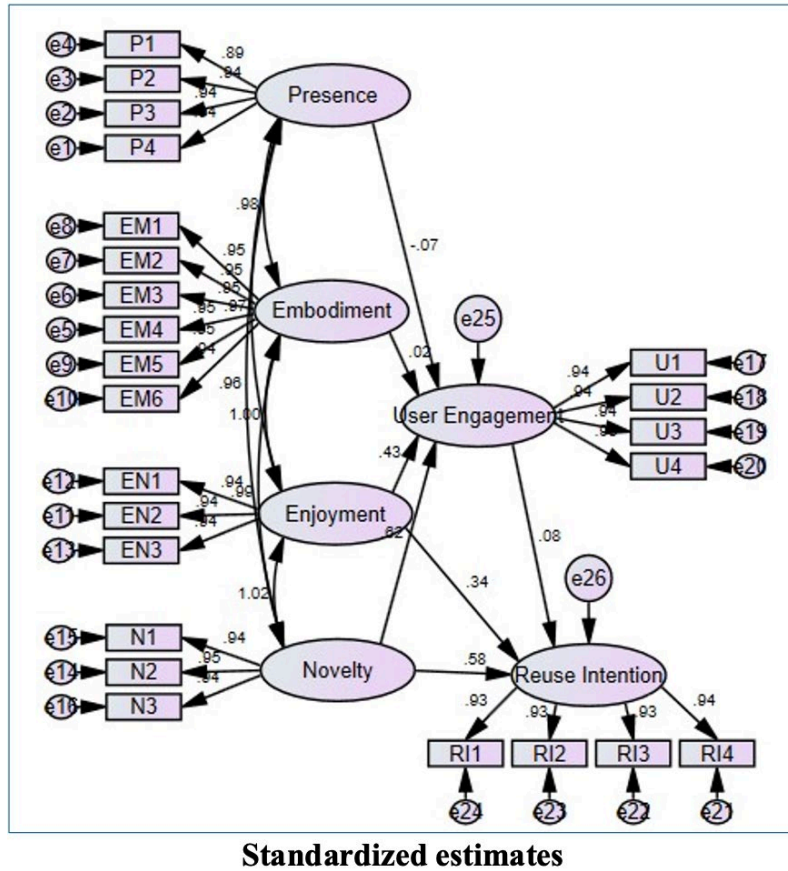


Figure 3. Structural model of the immersive learning environment, user engagement, and reuse intention

As Table 5 shows, enjoyment and novelty influenced user engagement, but presence and embodiment did not. Furthermore, enjoyment, novelty, and user engagement played a role in reuse intentions. These findings contributed to the qualitative research, which is outlined in the following section.

Table 5. Hypothesis test outcomes

Hypothesis	Statement	Outcome
1	Presence has a positive effect on user engagement in the immersive learning environment.	Not supported
2	Embodiment has a positive effect on user engagement in the immersive learning environment.	Not supported
3	Enjoyment has a positive effect on user engagement in the immersive learning environment.	Supported
4	Novelty has a positive effect on user engagement in the immersive learning environment.	Supported
5	Enjoyment has a positive effect on reuse intentions for the immersive technology.	Supported

Hypothesis	Statement	Outcome
6	Novelty has a positive effect on reuse intentions for the immersive technology.	Supported
7	User engagement has a positive effect on reuse intentions for the immersive technology.	Supported

EXPERT INTERVIEWS

Following the completion of the quantitative assessment, expert interviews were conducted among science and technology teaching experts ($n = 3$). The interviews revealed that the use of immersive environments in teaching was limited, as was the use of technology in general. In School 1, students did not typically have access to their own devices and were not provided with them, and most technology teaching is traditional and lab-based, with no use of AR or VR. School 2 does provide students with tablets, but teachers set their own curriculum and teaching practices and may or may not use AR or VR. Overall, most did not. School 3 does not provide devices or use AR or VR in teaching; instead, it follows traditional technology teaching practices. Overall, the schools were not heavily engaged in the use of immersive learning, and most had limited instruction in technology or using technology overall.

Impressions of the software were positive but qualified by cost concerns. School 1's expert felt that the software was suitable for supplementary learning and that the material was appropriate. It was noted as being potentially useful when students were moving into higher education, as it would help them gain practice using technologically driven learning environments. School 2's expert felt that the software would be suitable for children who are reluctant to ask questions, as it provided a route to self-discovery. Additionally, it was suitable for students hoping to build their technology skills alongside their science knowledge. School 3's expert also felt it was appropriate for self-study and test preparation as well as learning. However, all three experts expressed concern about the cost of the software, citing cost as one of the main reasons it may not be adopted. School 1's expert noted that, given low levels of funding in public schools, it was unlikely to be purchased for use. School 2 is a private school, but even so, School 2's experts felt that 50,000 baht (or approximately 50 baht per pupil) was the most the school could pay for it. School 3's expert felt that 500 baht per student would be suitable. Overall, therefore, while it did have some benefits, the software was viewed as very expensive given the potential benefits. These findings can be understood in the context of the literature review, as discussed next.

DISCUSSION

The evaluation of the research hypotheses found some findings that were consistent with what was expected, but others were inconsistent. Of particular note is that presence had a limited effect on user engagement, as did embodiment. These two factors have been associated with user engagement in past studies (Elwood, 2018; Gelsomini et al., 2020; Han, 2020; Kang et al., 2021; Lindgren et al., 2013, 2016). However, it is notable that, except for Han (2020), these studies used AR tools based on mobile devices or even conversion of entire spaces using a combination of mobile devices and projectors to transform an entire space. This is a more immersive approach than the desktop-based VR used here or in Han's (2020) study (Hung et al., 2021). However, it is also more expensive, and as the expert interviews indicated, the cost of implementation is of significant concern for schools that might consider implementing such a technology. Therefore, this requires balancing the effectiveness of the technology in promoting user engagement and the actual usability of the technology under realistic budget and space constraints for primary schools.

The research showed that enjoyment and novelty were associated with user engagement, as well as with reuse intention. Both of these are novel findings to some extent. Enjoyment has been associated with engagement in learning in other contexts (Guo, 2021; Imlig-Iten & Petko, 2018) but had weaker evidence for a reuse intention, with authors identifying mainly indirect relationships (Bueno et al.,

2020; Rodríguez-Ardura & Meseguer-Artola, 2016). Novelty has only had indirect evidence for an effect on engagement (Innocenti et al., 2019; Salar et al., 2020), as well as for an effect on reuse intention (Hamari et al., 2019; Song et al., 2019). This study suggests that these aspects of the immersive learning environment could have a stronger influence among young learners than they have been found to have among older learners, a possibility that should be investigated.

Finally, the study confirmed that user engagement did influence reuse intention. This finding was supported in some other studies (Gelsomini et al., 2020; Jung & Lee, 2018), but this research provides much more direct evidence for such a relationship. However, it should be considered that this effect was overall weak, although it is unclear why. It is possible that the children's age and perceived low levels of control over reuse may have affected reuse intention, as reuse intention depends on factors like perceived control over the decision (Choi & Sun, 2016). This is an area which requires more research. Suggestions for future research, as well as the implications of the study, are discussed next.

IMPLICATIONS

The study has some academic and practical implications. One academic implication is that it highlighted how Oprean and Balakrishnan's (2020) model of learning engagement can be operationalized and integrated into technology usage models to investigate outcomes like continuance intention. For example, learning engagement could be used as a specific construct in order to investigate continuance intention for other forms of immersive learning and technology-based learning. Given that this was one of the major gaps in the research, with only a few other studies investigating it, this is worth undertaking. Another academic implication is that enjoyment and novelty cannot be overlooked as sources of continuance intention for technology. Although their effects may differ in different technology contexts, it is worth examining what role they play, especially in technologies like AR, which are designed to have an emotional impact (Soon et al., 2023). With respect to practical implications, the study showed that AR does have value for primary learners, promoting engagement in the learning process and continuance intention for the technology itself. At the same time, the expert interviews revealed several barriers to adoption, particularly the cost of software. Therefore, even if AR is a useful tool for learners, it may struggle for adoption in light of constrained school budgets. This is a significant issue for the conclusion of the research.

While these findings were specific to Thailand, the findings do have some global applicability for developing immersive learning tools for elementary learners. First and foremost, immersive learning tools need to be developed with sensitivity to the plausible level of technology in the elementary classroom. Technology in elementary classrooms may not be as limited as it is in the Thai schools studied, but it is also unlikely to be extensive. Therefore, immersive learning tools need to be designed with this in mind. Furthermore, enjoyment was a determining factor in engagement and reuse intention. Therefore, immersive learning tools should, above all, be fun for the users.

CONCLUSION

The investigation of immersive learning among primary school students is still in its beginning stages of development. This research, building on prior studies, has shown that primary school children find immersive learning engaging and do form reuse intentions for the technology. Furthermore, the study shows that the characteristics of the immersive learning environment itself, including presence, embodiment, enjoyment, and novelty, do contribute to user engagement within the environment. However, the research findings illustrate that the implementation of immersive learning in primary schools may not be straightforward. The expert interviews revealed that most schools were not using immersive technology and furthermore did not have the resources to do so. Therefore, there is still more research and development, and more assignment of resources needed before immersive learning is a pragmatic learning group for the primary level.

This research has contributed to the literature by investigating immersive learning in a relatively unusual group. It has shown that primary learners may be different in terms of the factors in their engagement and what determines their reuse intentions for technology than older learners. The study also contributes pragmatically by illustrating both the value that immersive learning could provide at the primary level and the limitations of implementing immersive learning. Furthermore, the study suggests that desktop-based immersive learning may not be as engaging as mobile device-based immersive learning. Therefore, future implementation of immersive learning at the primary level may need to focus on mobile device-based learning.

There were some limitations to this research. The findings were based on a single trial of the software, which had not been fully developed at the time of implementation. Furthermore, the study was conducted amongst a group of experienced immersive technology users who regularly used immersive games. This could affect the influence of novelty on the reuse intention, as it has previously been suggested that naïve users may have different responses than experienced users. The research presented here was only part of a larger project, and findings are still emerging from this project. Thus, later findings may lead to critical reassessment of these early-stage findings.

Opportunities for future research arise from this study. The first opportunity for future research is a more extensive investigation into user engagement among young learners. This research suggests that primary school learners may be motivated by and engaged by different aspects of immersive learning than their university-level counterparts, who have been the main focus of most prior research. Therefore, additional research into how younger students engage with immersive learning environments would be appropriate to better understand some of the different findings that occur when younger students are investigated. Another opportunity for additional research is a comparison of desktop-based, mobile device-based, and environment-based AR to evaluate different effects on user engagement and learning outcomes. Previously, most studies have only investigated outcomes in a single environment, so it is difficult to determine whether, for example, user presence and embodiment are different when using different technologies and what impact this may have on learning.

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